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(54) **FAIL-SAFE COMMAND DESTRUCT SYSTEM**

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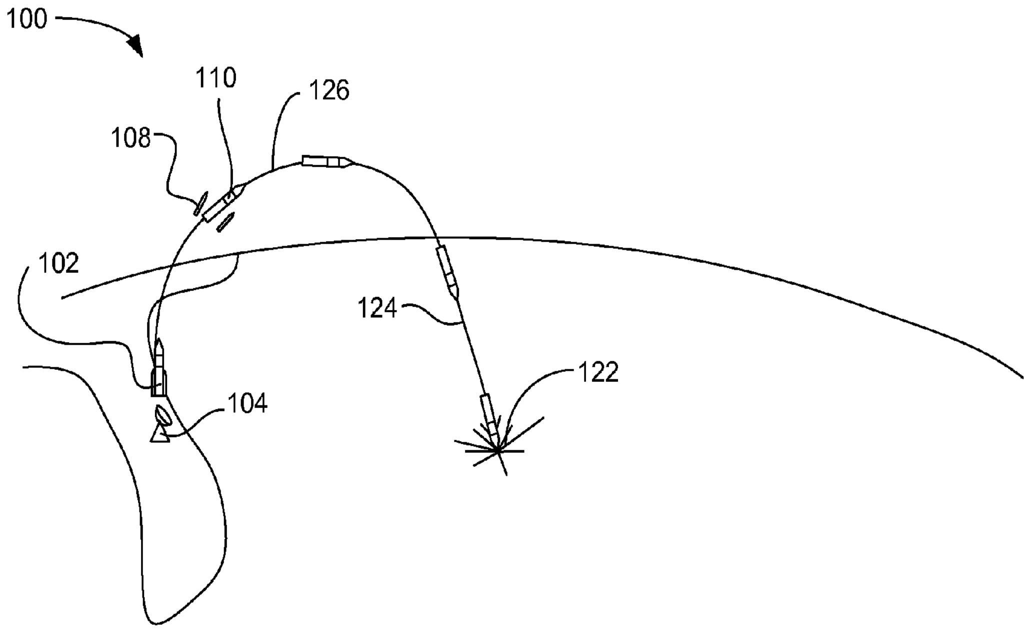
B64G 1/00	(2006.01)

(52) **U.S. Cl.**

CPC ***B64G 1/24*** (2013.01); ***B64G 1/002*** (2013.01); ***B64G 1/52*** (2013.01)

(57) **ABSTRACT**

A fail safe command destruct system for a multi-stage rocket comprising a first stage flight termination system and an upper stage command enable system. The flight termination system has the added feature that the same battery is the sole power source to the flight termination receiver and to a normally off flight inhibitor that requires power to permit engine operation. The command enable system has a normally inhibiting flight inhibitor that requires power to permit engine operation. The same battery is the sole source of power to the command enable receiver and the flight inhibitor such that battery failure prevents engine ignition. Lack of a command from outside the rocket to the command enable receiver also prevents engine ignition.



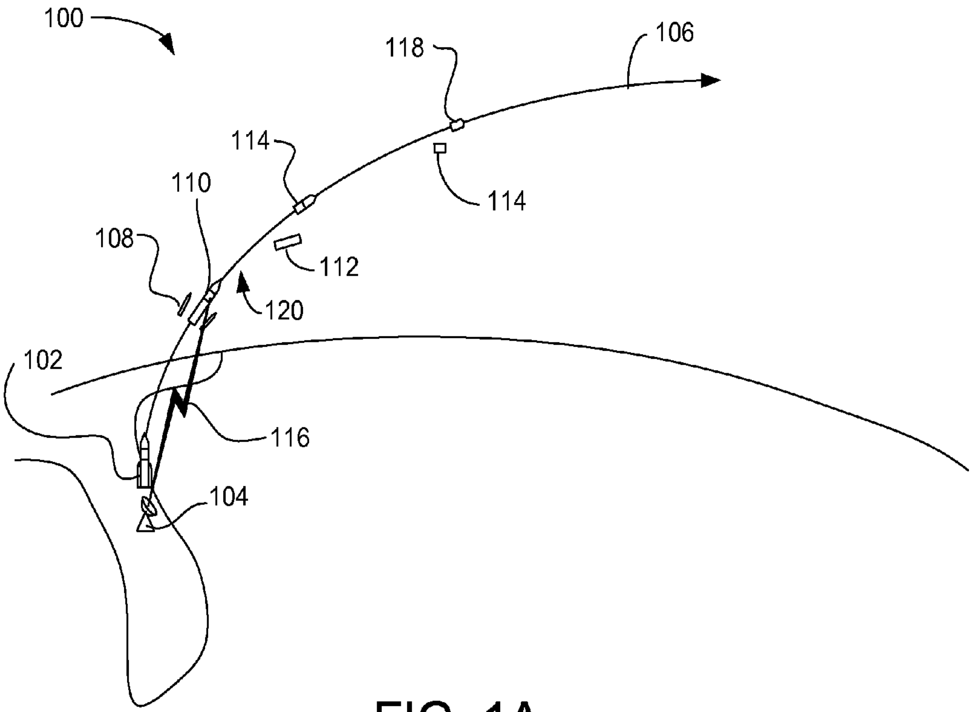

100
106
118
114
114
110
108
112
120
102
116
104

FIG. 1A

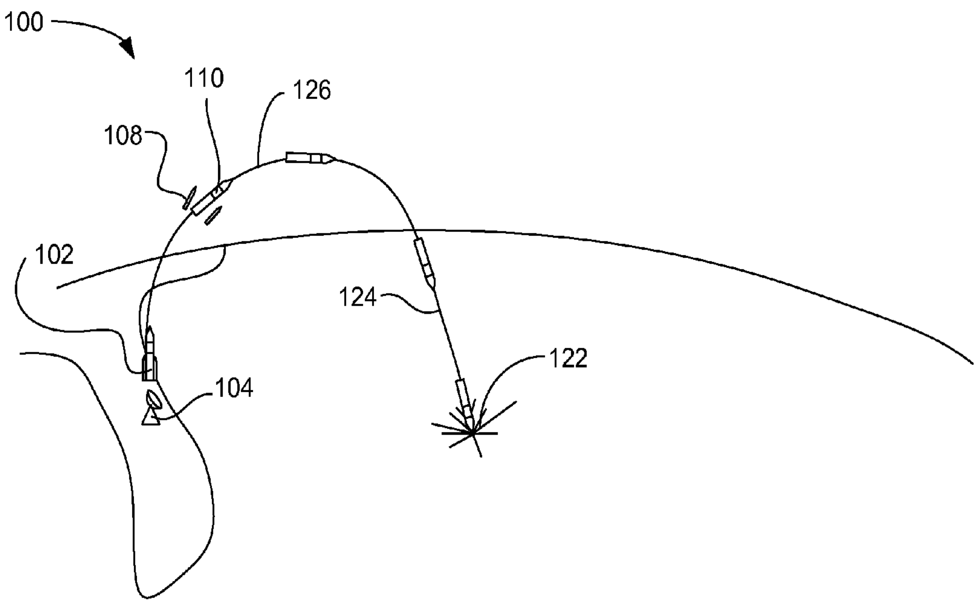

100
110
126
108
102
124
122
104

FIG. 1B

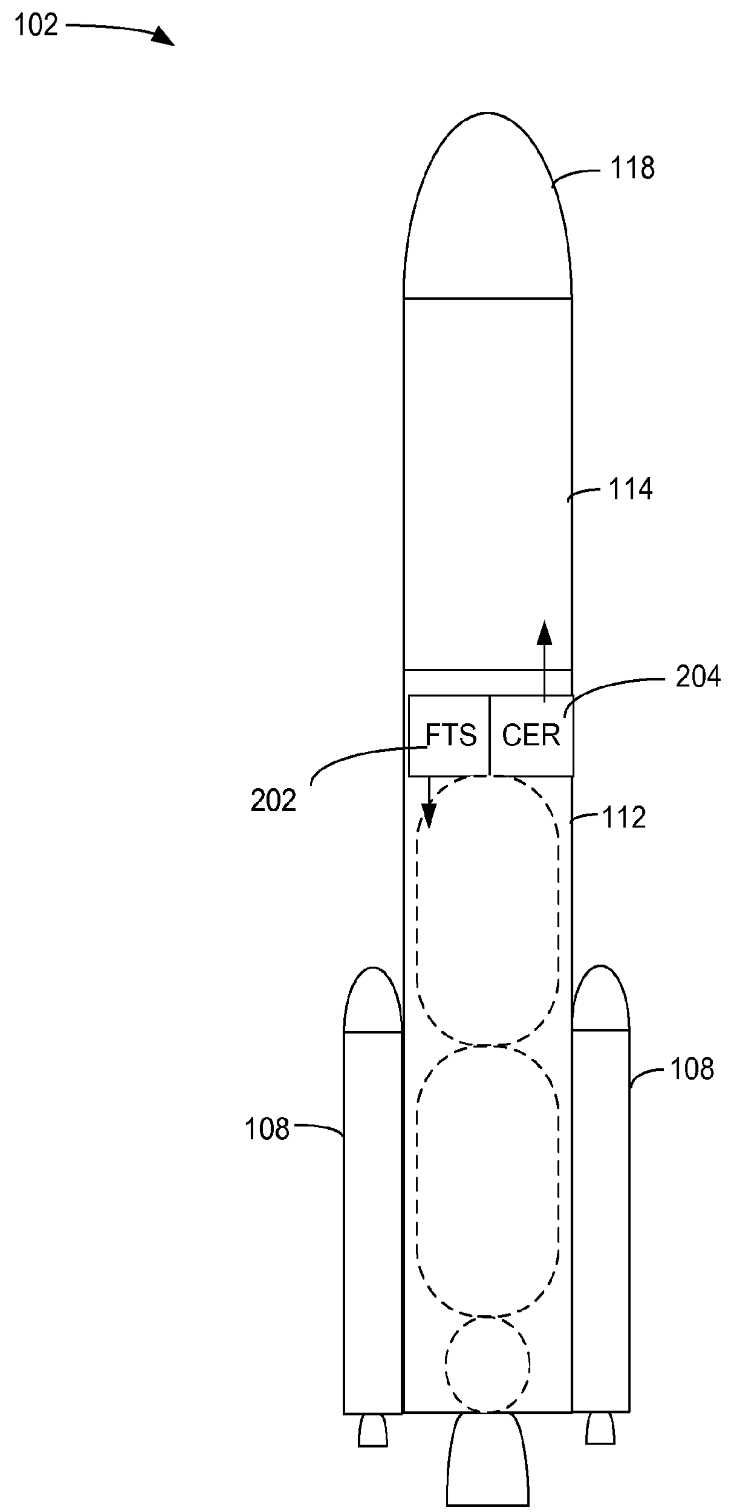


FIG. 2

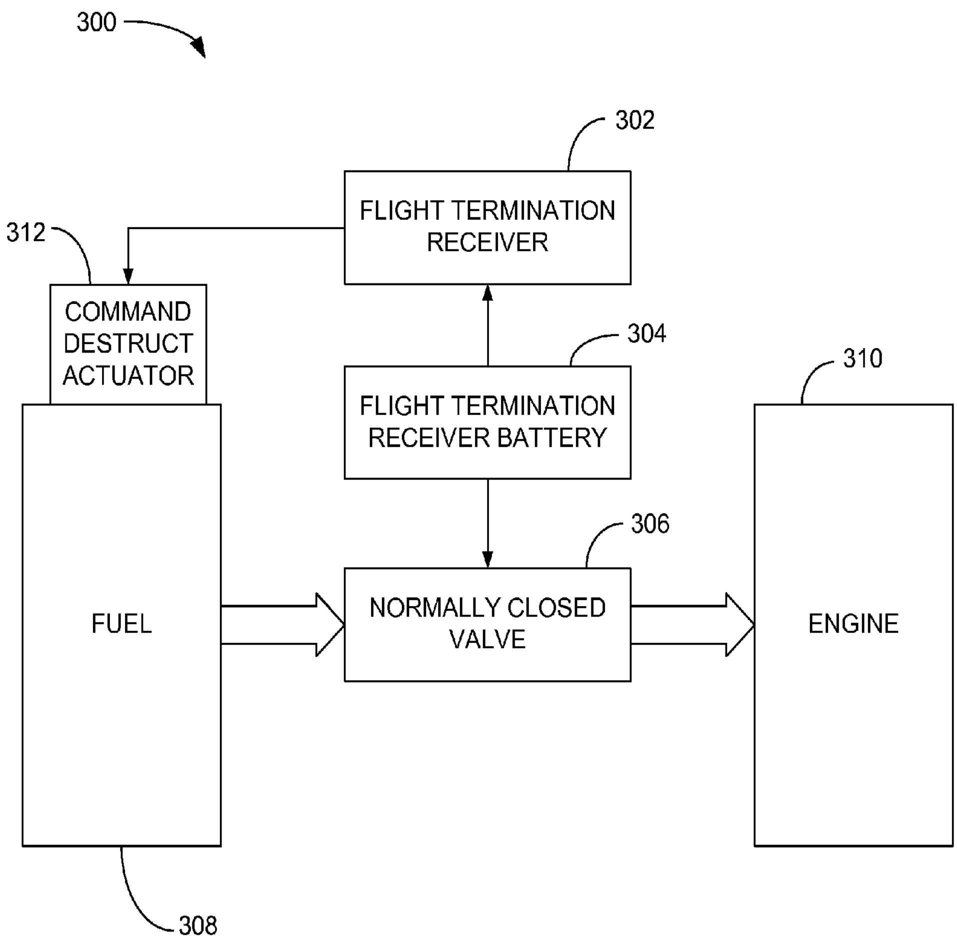

300
302
FLIGHT TERMINATION RECEIVER
312
COMMAND DESTRUCT ACTUATOR
304
FLIGHT TERMINATION RECEIVER BATTERY
310
306
FUEL
NORMALLY CLOSED VALVE
ENGINE
308

FIG. 3

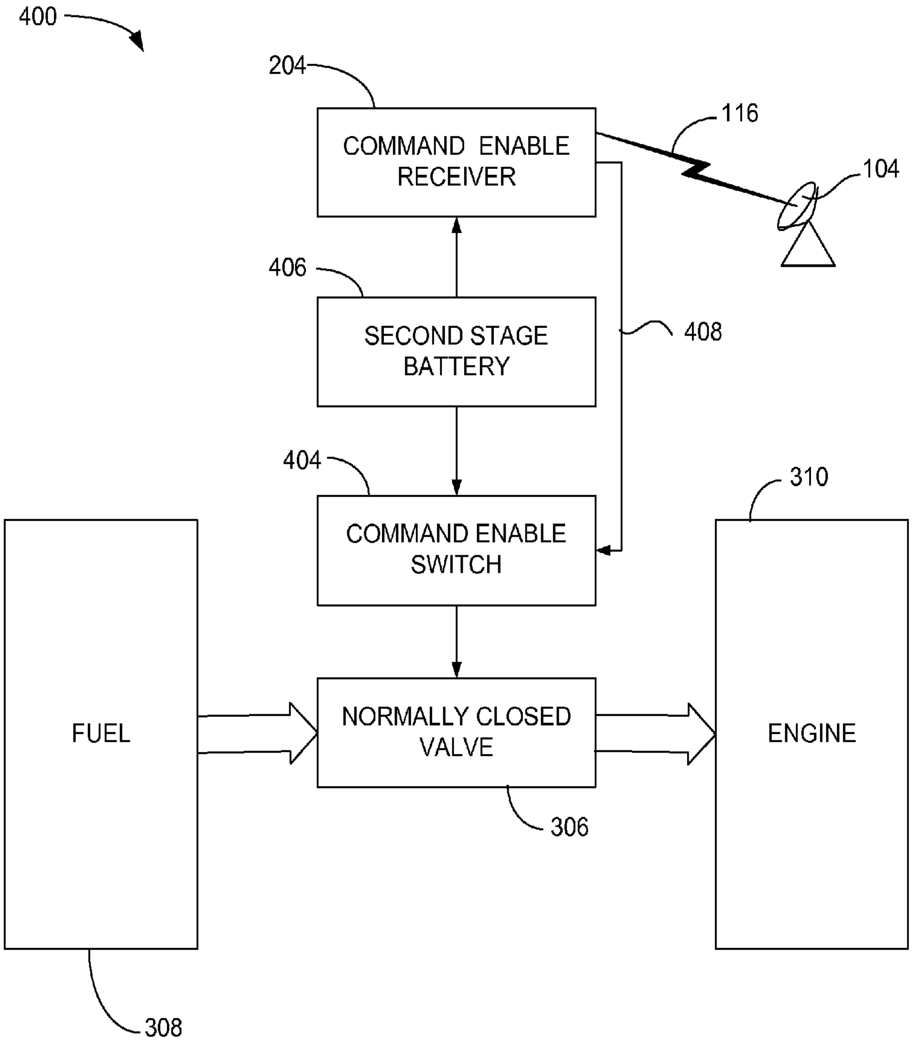

400
204
COMMAND ENABLE RECEIVER
116
104
406
SECOND STAGE BATTERY
408
404
COMMAND ENABLE SWITCH
310
FUEL
NORMALLY CLOSED VALVE
ENGINE
306
308

FIG. 4

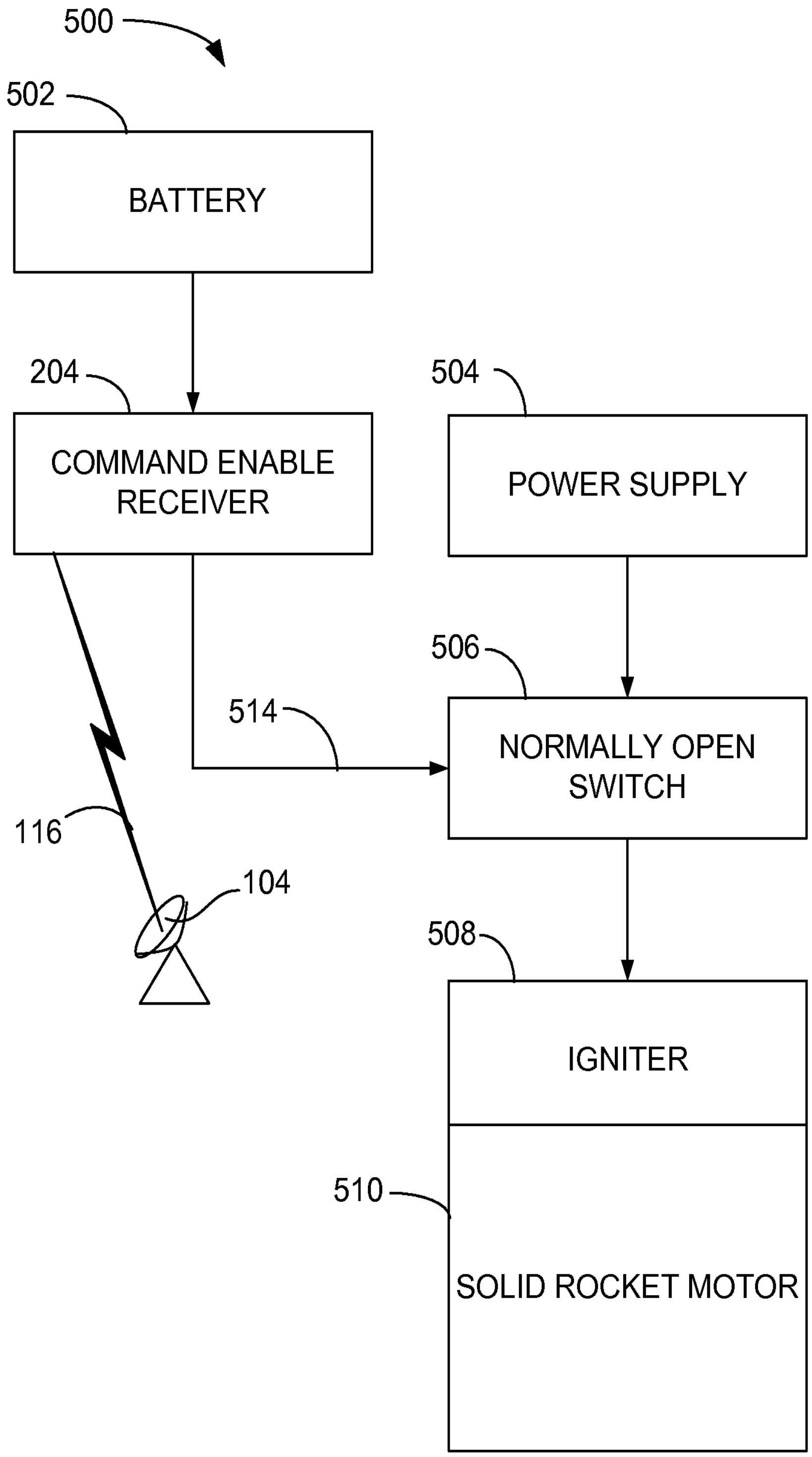

500
502
BATTERY
204
COMMAND ENABLE RECEIVER
504
POWER SUPPLY
506
514
NORMALLY OPEN SWITCH
116
104
508
IGNITER
510
SOLID ROCKET MOTOR

FIG. 5

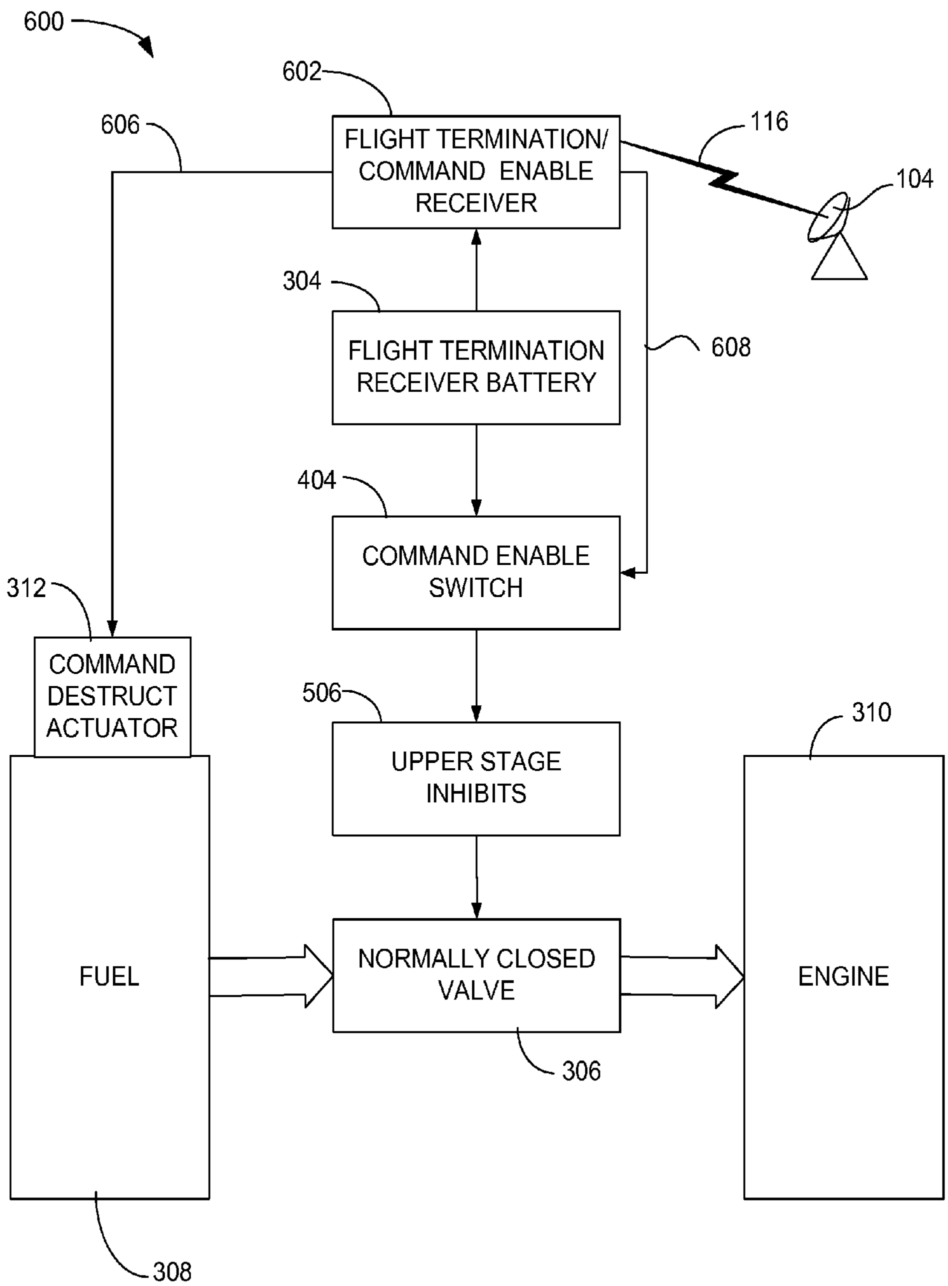

600
602
FLIGHT TERMINATION/ COMMAND ENABLE RECEIVER
606
116
104
304
FLIGHT TERMINATION RECEIVER BATTERY
608
404
COMMAND ENABLE SWITCH
312
COMMAND DESTRUCT ACTUATOR
506
UPPER STAGE INHIBITS
310
FUEL
NORMALLY CLOSED VALVE
ENGINE
306
308

FIG. 6

FAIL-SAFE COMMAND DESTRUCT SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. provisional patent application Ser. No. 62/040,248 filed Aug. 21, 2014 to the same inventor.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

[0002] This invention was made with government support under contract FA8650-12-C-7274 awarded by the US Air Force. The government has certain rights in the invention. The research in this document was developed with funding from the Defense Advanced Research Projects Agency (DARPA). Distribution Statement A: Approved for Public Release, Distribution Unlimited.

FIELD OF ART

[0003] The present invention relates to a fail-safe flight termination system (FTS) for multi-stage launch vehicles. The present invention also relates to an FTS that uses a common FTS receiver battery to open normally closed fuel valves. The present invention also relates to use of inhibits to render the upper stage of a multi-stage launch vehicle non-propulsive until a ground-based command is sent to activate the propulsion system after the upper stage reaches a safe point in the trajectory.

SUMMARY OF THE INVENTION

[0004] Briefly described the invention includes methods for making safe stages on launch vehicles (rockets). In one embodiment for liquid-fueled stages, a normally closed valve is kept open by power from a common flight termination receiver battery, such that failure of the flight termination receiver battery closes the fuel valve to the engine, shutting down the engine in a fail-safe mode. In a second embodiment for a liquid-fueled or solid rocket that is deemed not to require an FTS on the upper stage, a command, wirelessly sent from the ground, must be received to remove ignition inhibits, thereby rendering the upper stage propulsive only after it has reached a safe point in the trajectory.

DESCRIPTION OF THE FIGURES OF THE DRAWINGS

[0005] The present invention will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and

[0006] FIG. **1**A is a perspective view illustrating an exemplary embodiment of the fail-safe command destruct system in a successful launch, according to a preferred embodiment of the present invention;

[0007] FIG. **1**B is a perspective view illustrating an exemplary embodiment of the fail-safe command destruct system of FIG. **1**A in an unsuccessful launch, according to a preferred embodiment of the present invention;

[0008] FIG. **2** is a diagrammatic view illustrating an exemplary embodiment of the fail-safe command destruct system of FIG. **1**A, according to a preferred embodiment of the present invention;

[0009] FIG. **3** is a block diagram illustrating an exemplary embodiment of the fail-safe command destruct system for the stages of a liquid-fueled rocket that are deemed to require an FTS, according to a preferred embodiment of the present invention;

[0010] FIG. **4** is a block diagram illustrating a second exemplary embodiment of the fail-safe command destruct system of FIG. **1**A for a liquid-fueled stage, according to a preferred embodiment of the present invention;

[0011] FIG. **5** is a block diagram illustrating an exemplary embodiment of the fail-safe command destruct system for a solid-fueled stage, according to a preferred embodiment of the present invention; and

[0012] FIG. **6** is a block diagram illustrating a third exemplary embodiment of the fail-safe command destruct system of FIG. **1**A for a liquid-fueled stage, according to a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0013] FIG. **1**A is a perspective view illustrating an exemplary embodiment of the fail-safe command destruct system **100** in a successful launch, according to a preferred embodiment of the present invention. Multistage launch vehicle **102** with strap-on solid rocket motors **108** (one of two illustrated is labeled) launches from the planet surface along ascent-to-orbit trajectory **106**. When the strap-on solid rocket motors have burned out, the strap-on solid rocket motors **108** separate from the main body **110** of the launch vehicle **102**. In this example only, solid rocket motor separation is taken as the point at which the main body **110** is in a range-safe state where, if the launch vehicle **102** fails past this point, the debris will not affect those on the ground. In various other embodiments, the safety gate may be reached before or after separation of the solid rocket motors. A command is sent via ground station **104** via communications link **116** to remove ignition inhibits on the second stage **114** prior to separation of the first stage **112** at point **120**. In a particular embodiment, the command can be sent from any source outside the rocket, such a ship, aircraft, or satellite.

[0014] The present invention is not limited to launch vehicles **102** with strap-on solid rocket motors **108** and, in various launch vehicle and payload configurations, the range-safe state may be reached independently of solid rocket motor separation on launch vehicles **102** that use strap-on rocket motors **108**, whether solid or liquid fueled. Furthermore, the present invention is not limited to surface-launched launch vehicles **102**, but may be used with air-launched multistage launch vehicles as well.

[0015] FIG. **1**B is a perspective view illustrating an exemplary embodiment of the fail-safe command destruct system **100** of FIG. **1**A in an unsuccessful launch, according to a preferred embodiment of the present invention. When the launch vehicle **102** is not in a range-safe state prior to second stage ignition, such as being on failed trajectory **126**, the command enable signal is not sent via link **116**, and so the second stage propulsion is always inhibited. The launch vehicle body **110** falls to Earth **122**, possibly becoming a debris cloud at some point **124**.

[0016] The command enable signal is sent via link **116** from the ground station **104** only if the launch vehicle **102** is in a range-safe state. The command enable signal may be generated automatically by a computer responsive to telemetry from the launch vehicle **102** and/or tracking data representing the launch vehicle trajectory **106**. In other embodiments, human intervention may be required to generate the

command enable signal. In some cases, the command may be sent from an airborne command facility or a shipboard command facility.

[0017] FIG. **2** is a diagrammatic view illustrating an exemplary embodiment of the fail-safe command destruct system of FIG. **1**A, according to a preferred embodiment of the present invention. The FTS **202** is in the first stage **112** and can destroy the first stage responsive to a command from the ground. Second stage **114** does not have an FTS **202**, as it would not normally fire until after first stage **112** has carried it past the range safety gate. First stage **112** has a command enable receiver (CER) **204**, which must receive a signal from outside the rocket to remove ignition inhibits in the second stage **114**. Any number of upper stages **114** may be coupled to the CER **204**. The CER **204** may also be combined with the FTS receiver **302** (see FIG. **3**) in a single piece of hardware.

[0018] FIG. **3** is a block diagram illustrating an exemplary embodiment of the fail-safe command destruct system **300** for the stages of liquid-fueled rocket that are deemed to require an FTS **202**, according to a preferred embodiment of the present invention. FTS **202** includes the flight termination receiver **302**, the flight termination receiver battery **304**, and the command destruct actuator **312**. Normally closed valve **306** is in the fuel line between the fuel tank **308** and the engine **310** and requires a supply of electrical power to hold valve **306** open to enable fuel to flow to the engine **310**. Valve **306** is kept open by constant power from the flight termination receiver battery **304**, which also powers the flight termination receiver **302**. If the flight termination receiver battery **304** fails during launch, the first stage **112** cannot receive a command destruct signal in the flight termination receiver **302** and so cannot activate the command destruct actuator **312** to destroy the vehicle (exemplified as blowing up the fuel tank **308**, but possible by various means known in the art). However, failure of the flight termination receiver battery **304** also causes valve **306** to close, cutting off the engine **310** and allowing the launch vehicle **102** to fall back to Earth **122**. Those of skill in the art, illuminated by the present disclosure, will understand that a normally closed valve **306** may, alternatively or additionally, be used to control the flow of oxidizer (not shown) to engine **310**. With the battery **304** operating correctly on an anomalous trajectory **126**, it is a judgment call for the range safety officer whether to bring down the vehicle **102** by not enabling (or cutting off) fuel and/or oxidizer flow to the engine **310** or by using the command destruct actuator **312**. The same common battery architecture may also be used in an autonomous flight safety system to simultaneously power the valves and the autonomous intelligence system on-board, such that any battery failure automatically shuts off the engines in a fail-safe mode.

[0019] FIG. **4** is a block diagram illustrating a second exemplary embodiment of the fail-safe command destruct system **400** of FIG. **1**A for a liquid-fueled upper stage, according to a preferred embodiment of the present invention. The command enable system includes the command enable receiver **204**, the upper stage battery (or equivalent power supply) **406** and the command enable switch **404**. The command enable receiver **204** (hereinafter "receiver **204**"), functions to receive a command enable signal via link **116** to responsively generate a signal **408** to remove ignition inhibits (illustrated as normally closed valve **306**) from the upper stage **114**. Power conducted by the closed command enable switch **404** preferably comes from the same battery **406** as supplies the CER **204** (as shown) or, in other embodiments, may come from an independent source. In either case, failure of the CER **204** or failure to receive the command enable signal prevents ignition of the second stage **114**.

[0020] FIG. **5** is a block diagram illustrating another exemplary embodiment of the fail-safe command destruct system **500** for a solid-fueled stage that is deemed not to require an FTS **202**, according to a preferred embodiment of the present invention. In this embodiment, an inhibit switch **506** is coupled between the power supply **504** and the igniter **508** of the solid rocket motor **510**. Switch **506** is closed by a signal **514** from the command enable receiver **204** on a lower stage. Solid rocket motor **510** may be an upper stage or a strap-on that is sequenced to fire after launch. Command enable receiver **204** on a lower stage receives a command enable signal via link **116** from ground station **104**, or elsewhere outside of the rocket, and generates signal **514** to close switch **506** responsive to the command enable signal. Thus, absent a command enable signal via link **116**, the upper stage igniter **508** cannot ignite the solid rocket motor **510**. The ignition inhibits are for upper stages that are not deemed to need an FTS **202** due to having ignition scheduled to occur past a predetermined safety point in the trajectory **106**. Battery **502** supplies power to the command enable receiver **204** on a lower stage. In a particular embodiment, the battery for the CER **204** may be the power supply **504**.

[0021] FIG. **6** is a block diagram illustrating a third exemplary embodiment of the fail-safe command destruct system **600** of FIG. **1**A for a liquid-fueled stage, according to a preferred embodiment of the present invention. Fail-safe command destruct system **600** is a hybrid system. The flight termination receiver **302** has been modified into combined flight termination receiver and command enable receiver **602** (hereinafter "receiver **602**"). Receiver **602** functions as a flight termination receiver **302** to receive a flight termination command via link **116** from ground station **104** and responsively generate a destruct signal **606** to command destruct actuator **312** to destroy the first stage **112** (illustrated as blowing up the fuel tank **308**, one of various methods known in the art). Receiver **602** also functions as a command enable receiver **204** (see FIG. **4**) to receive a command enable signal via link **116** to responsively generate a signal **608** to remove upper stage inhibits **506** such as normally closed valve **306**.

[0022] Those of skill in the art, enlightened by the present disclosure, will be aware of obvious variations of the described embodiments, all of which are within the scope of the claims below.

1. A fail-safe command destruct system for a rocket, the system comprising:

a. a flight termination system; and

b. a command enable system.

2. The system of claim **1**, wherein said command enable system comprises:

a. a wireless command enable receiver operable to receive a signal from a source external to said rocket;

b. an ignition inhibitor operable to inhibit ignition of a second or higher stage rocket engine of a multi-stage rocket; and

c. a command enable switch operable, responsive to a signal from said command enable receiver, to change the state of said ignition inhibitor.

3. The system of claim **2**, a power source operable as the sole source of power to said command enable switch, and command enable receiver, and said ignition inhibitor.

4. The system of claim **2**, wherein said ignition inhibitor comprises a normally closed fluidic valve, requiring application of power to remain open.

5. The system of claim **4**, wherein said normally closed fluidic valve comprises a fuel valve.

6. The system of claim **4**, wherein said normally closed fluidic valve comprises an oxidizer valve.

7. The system of claim **2**, wherein said ignition inhibitor comprises a normally open electrical switch in an ignition circuit.

8. The system of claim **1**, wherein said flight termination system comprises:

a. a flight termination receiver powered from a first stage power source and operable to receive a command destruct signal from outside said rocket;

b. a command destruct actuator responsive to a signal from said flight termination receiver to destroy or terminate the flight of said rocket;

c. a flight inhibiter requiring a constant source of power to permit flight; and

d. said first stage power source operable as the sole source of power to both the flight termination receiver and the flight inhibiter.

9. The system of claim **1**, wherein said flight termination system is at least partially collocated with said command enable system.

10. A fail-safe command destruct system for a rocket, the system comprising:

a. a flight termination system comprising:

i. a flight termination receiver powered from a first stage power source and operable to receive a command destruct signal from outside or within said rocket;

ii. a command destruct actuator responsive to a signal from said flight termination receiver to destroy or terminate the flight of said rocket;

iii. a flight inhibiter requiring a constant source of power to permit flight; and

iv. said first stage power source operable as the sole source of power to both the flight termination receiver and the flight inhibiter; and

b. a command enable system.

11. The system of claim **11**, wherein said flight termination system is at least partially collocated with said command enable system.

12. The system of claim **11**, wherein said command enable system comprises:

a. a wireless command enable receiver operable to receive a signal from a source external to said rocket;

b. an ignition inhibitor operable to inhibit ignition of a second or higher stage rocket engine of a multi-stage rocket; and

c. a command enable switch operable, responsive to a signal from said command enable receiver, to change the state of said ignition inhibitor.

13. The system of claim **11**, a power source operable as the sole source of power to said command enable switch, said command enable receiver, and said ignition inhibitor.

14. The system of claim **13**, wherein said ignition inhibitor comprises one of:

a. a normally closed fluidic valve, requiring application of power to remain open and wherein said normally closed fluidic valve comprises at least one of a fuel valve and an oxidizer valve; and

b. a normally open electrical switch in an ignition circuit, requiring application of power to remain closed.

15. A fail-safe command destruct system for a rocket, the system comprising:

a. a flight termination system; and

b. a command enable system comprising:

i. a wireless command enable receiver operable to receive a signal from a source external to said rocket;

ii. an ignition inhibitor operable to inhibit ignition of a second or higher stage rocket engine of a multi-stage rocket;

iii. a command enable switch operable, responsive to a signal from said command enable receiver, to change the state of said ignition inhibitor; and

iv. a power source operable as the sole source of power to said command enable switch, said command enable receiver, and said ignition inhibitor.

16. The system of claim **15**, wherein said ignition inhibitor comprises one of:

a. a normally closed fluidic valve, requiring application of power to remain open and wherein said normally closed fluidic valve comprises at least one of a fuel valve and an oxidizer valve; and

b. a normally open electrical switch in an ignition circuit, requiring application of power to remain closed.

17. The system of claim **15**, wherein said flight termination system comprises:

a. a flight termination receiver powered from a first stage power source and operable to receive a command destruct signal from outside or within said rocket;

b. a command destruct actuator responsive to a signal from said flight termination receiver to destroy said rocket;

c. a flight inhibiter requiring a constant source of power to permit flight; and

d. said first stage power source operable as the sole source of power to both the flight termination receiver and the flight inhibiter.

18. The system of claim **15**, wherein said flight termination system is at least partially collocated with said command enable system.

19. A fail-safe command destruct system for a rocket comprising a common battery configured to supply power to a flight termination receiver and a flight termination actuator, wherein said flight termination actuator is operable to terminate flight on the occurrence of one of:

a. battery failure; and

b. receipt of a destruct command in the command destruct receiver.

20. A fail-safe command destruct system for a rocket comprising an upper stage of a multistage rocket that is non-propulsive until an enabling command is received from outside said rocket.

* * * * *